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RESEARCH DEPARTMENT **REPORT**

A digital field strength measuring receiver for l.f. and m.f.

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SUMMARY

The measuring receiver described gives a direct reading of field strength in decibels relative to 1 μV/m for both the electric and the magnetic field components in the l.f. and m.f. broadcast bands. Digital techniques are used extensively to give simple and reliable operation. The receiver is suitable for making measurements on the move in a car, and an omni-directional magnetic field detector is provided.

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CP Sandbank

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1. INTRODUCTION

There has been renewed interest in the l.f. and m.f. bands, both for propagation study and for planning services. Existing receivers are difficult to tune and calibrate and cannot collect many measurements quickly. They are usually designed to measure the magnetic field only. These factors led to the design and construction of a new receiver and associated equipment.* This report gives an outline description of the equipment.

The "readout," of field strength in decibels relative to 1 μV/m, in digital form, is derived from a system first developed for u.h.f. measuring receivers.[1,2] This system was also incorporated in Band II receivers.[3] However, much additional work was needed to produce an l.f. / m.f. receiver, not least of which was the design of an omnidirectional detector of magnetic fields.

The system is primarily designed for easy mounting into any car. The aerials are fixed to a roof rack and can be quickly adapted for electric or magnetic fields for either m.f. or l.f. Continuous records of field strength variation along the route are made by feeding the receiver output to an analyser[4] and/or a chart recorder. The association of field record with location is achieved by putting a device in the car's speedometer cable which optically detects the distance travelled and passes pulses to the recording equipment.

2. SPECIFICATION OF THE RECEIVER AND AERIAL SYSTEM

Frequency coverage:		
	LF band:	148 – 284 kHz
	MF band:	519 – 1607 kHz
Field strength range:		
	H fields:	27 – 138 dB (rel. to $1/120\pi$ μA/m)
	E fields:	28 – 131 dB (rel. to 1 μV/m)
Receiver input impedance:	~ 50 ohms	
I.F.:	10.7 MHz (oscillator high)	
Image rejection:	$\geqslant$ 80 dB	
Unwanted signal level to cause onset of mixer overload:		
	35 mV at receiver input (input attenuator set to "-20dB OUT")	
	350 mV at receiver input (input attenuator set to "-20dB IN")	
Frequency selection:	by 4 b.c.d. thumbwheel switches in 1 kHz steps	
Output:	25 way D-socket provides field strength in binary coded decimal (b.c.d.) and a ranged analogue output for a recording milliammeter.	
Audio:	Built-in loudspeaker. Output (600 ohms) via jack socket, d.c. coupled to detector	
Indicators:	Digital display in decibels (for E rel. to 1 μ V/m; for H rel. to $1/120\pi$ μA/m)	

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*The initial design study was carried out by S.R. Ely.

Gain control:	By digital logic: 76.6 dB of binary switched I.F. gain and 25.6 dB switched r.f. attenuator Manual: 20 dB via front panel switch
Calibration oscillator:	A front panel output, actuated by a red push switch, gives a square wave at the selected frequency, which has 100 mV r.m.s. fundamental component.
Set calibration:	A screwdriver pre-set control not normally requiring adjustment (see Appendix)
Remote aerial tune:	A 15 way D-socket gives an 8 bit output, controlled by frequency selection switches, which operates a binary set of tuning capacitors.
Power supplies:	Input either 10–17V negative earth vehicle supply or 240V 50 Hz mains (fused at 5A and 500 mA respectively). Outputs -7V, 18V and 38V unstabilised, 8V and 12.5V stabilised.
Temperature range:	0°C to 40°C
Weight:	13 kg
Dimensions:	530 x 300 x 210 mm
Aerial tuning capacitors:	Binary set giving from 0 – 1275 pF in 5 pF steps
Head amplifiers:	Described in Reference 5 (give high linearity, low intermodulation products)
Current source:	R.F. current supply for calibration
MF loops:	2 crossed loops closely matched, to give omni-directional pattern within ± 2dB. Tap allows calibration feed via a relay
LF Loops:	Similar to m.f. loops
Whip aerial:	1.6m long giving comparable output to loops. Switched changeover between l.f. and m.f. by inserting inductors which allow tuning by the same capacitors as for loops. Calibration signal injected via taps on inductors.

3. DESCRIPTION OF THE AERIAL SYSTEM

A block schematic of the aerial system is given in Fig. 1. There is a "bottom box" which contains the tuning capacitors, head amplifiers and calibration current source. Into this "bottom box" may be plugged 3 types of aerial unit: m.f. loops, l.f. loops and a whip aerial for l.f. or m.f.

The tuning capacitors are switched in by relays controlled from the receiver. They consist of a bank of eight, enabling a range of 0 – 1275pF to be obtained in 5pF steps. The head amplifiers allow a high impedance from the aerials to be converted to a low impedance feed to the receiver, without introducing significant intermodulation products. These amplifiers are described in Reference 5. The current sources provide an r.f. current supply for calibration purposes.

Magnetic field is measured at m.f. by having two crossed loops trimmed to give a close match in inductance and capacitance, so that they may be combined to give an omni-directional pattern to within ± 2dB. There is a relay system within the aerial unit which, when energised, feeds a calibration signal to a tap on the loop. In this way the whole system may be checked including the aerial itself.

Magnetic fields at l.f. are measured by plugging in a similar aerial to that described for m.f. However, in this case the aerial contains more turns to provide a greater inductance. This increase in turns necessitates a small vertical displacement of the loops, relative to each other, to allow a clear passage of the wires with little crosstalk. (See Fig. 2(a)).

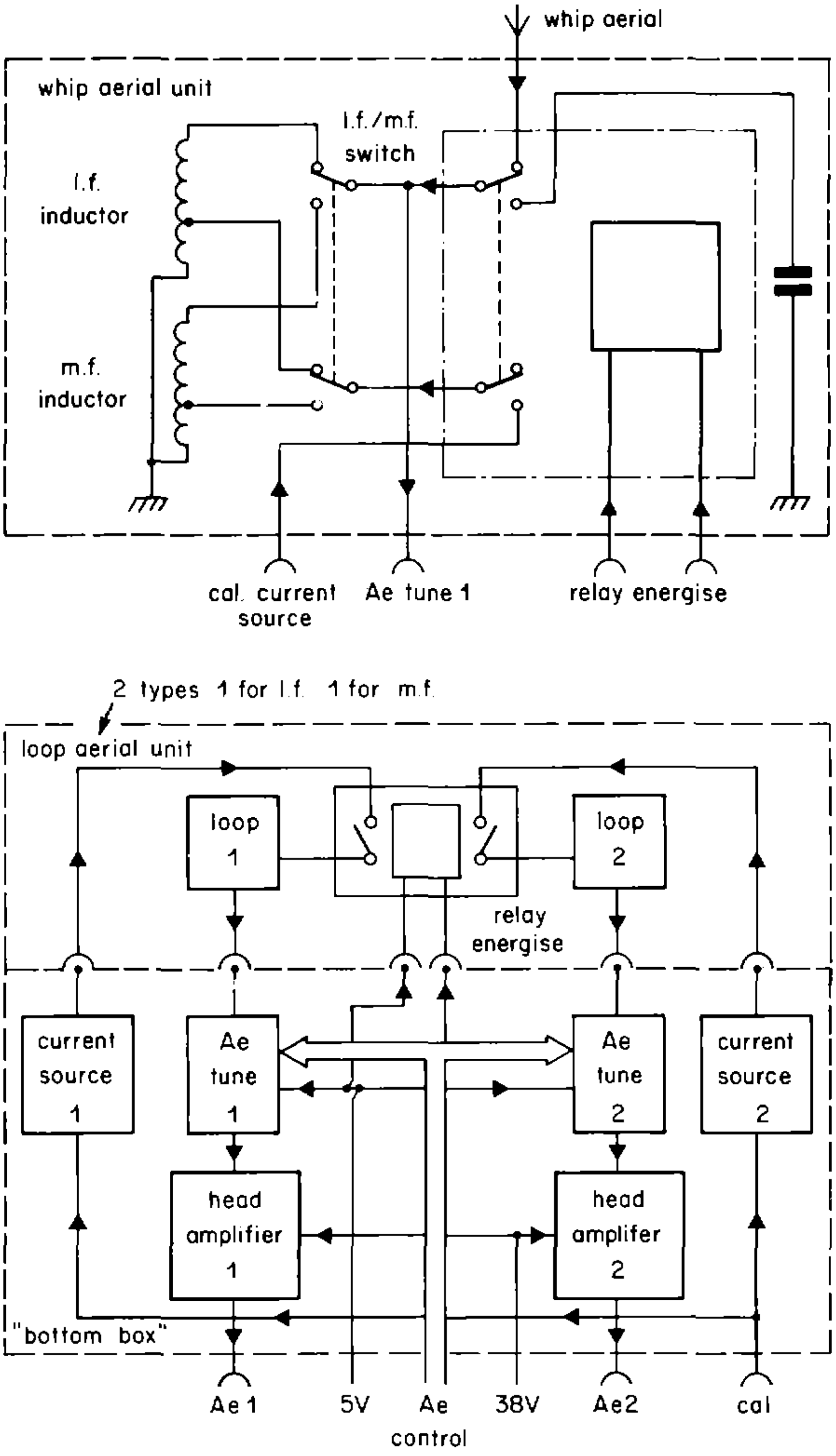

Fig. 1 - Block schematic of aerial system.

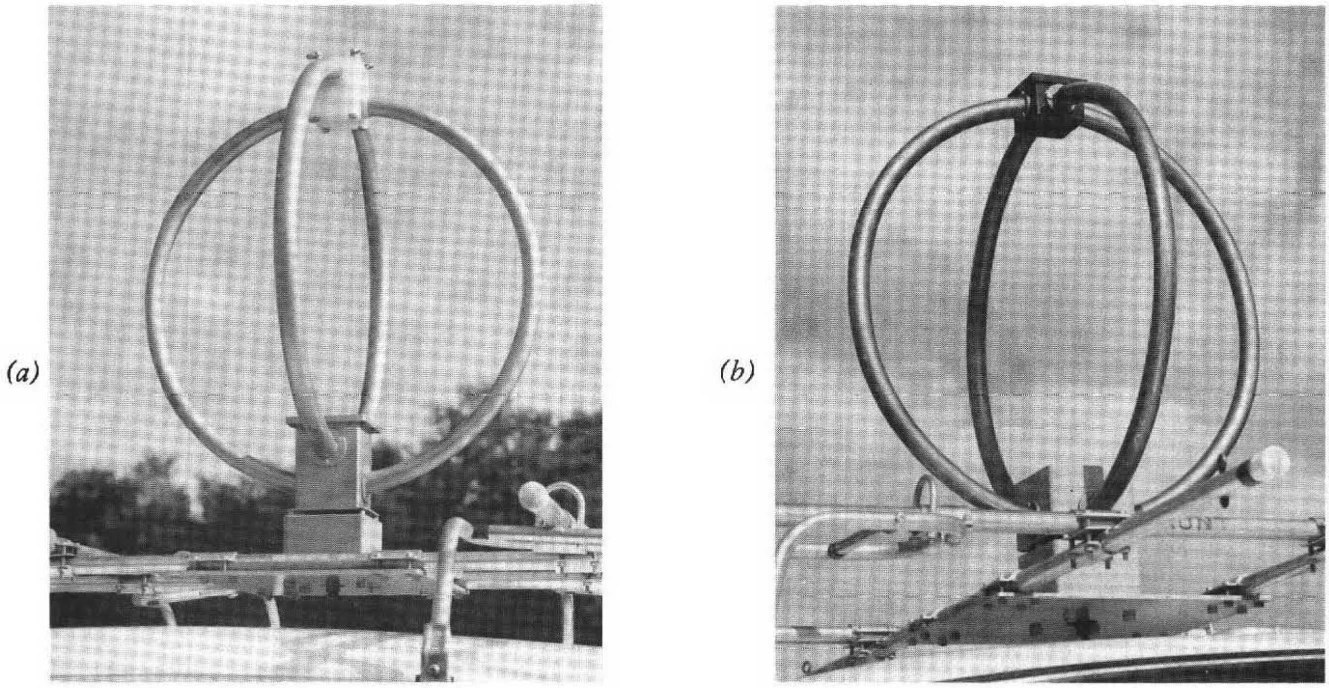

Fig. 2 - Loop aerials mounted on a car (a) l.f. (b) m.f.

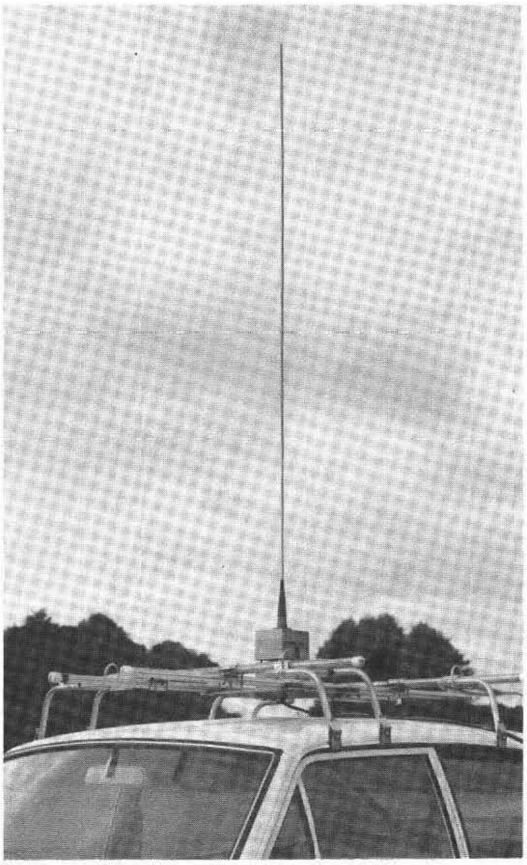

Fig. 3- Whip aerial mounted on a car (note this is a prototype with a 2m whip).

The whip aerial is 1.6 metres long and provides an output comparable to that from the loops. Tuning is provided by means of a coil connected from the base of the aerial to earth. There are two coils provided, one for m.f. and one for l.f., these being selected by a waterproof switch operated from the outside of the aerial box. The coils have inductances made equal to the loop aerial inductances so that the same capacitor values may be used for both whip and loop tuning. The coils have taps for the insertion of the calibration signal when the relays are activated. This is similar to the loop system testing procedure, but in this case it must be remembered that the whip itself is not being tested.

Fig. 2 shows the magnetic field detecting aerials mounted on a car. Fig. 2(a) is the l.f. version and Fig. 2(b) the m.f. In each case the roof rack may be seen, and the "bottom box" containing the tuning capacitors and head amplifiers. Fig. 3 shows the whip aerial for electric field detection at both l.f. and m.f.

4. DESCRIPTION OF THE RECEIVER

A block schematic of the receiver is given in Fig. 4. There are two aerial inputs ("Ae 1" and "Ae 2"), one for each of the crossed loops. The "Ae 1" input is used also for the whip aerial. The inputs feed into low pass filters which are flat within ± 0.2dB up to 1.36MHz, 1dB down at

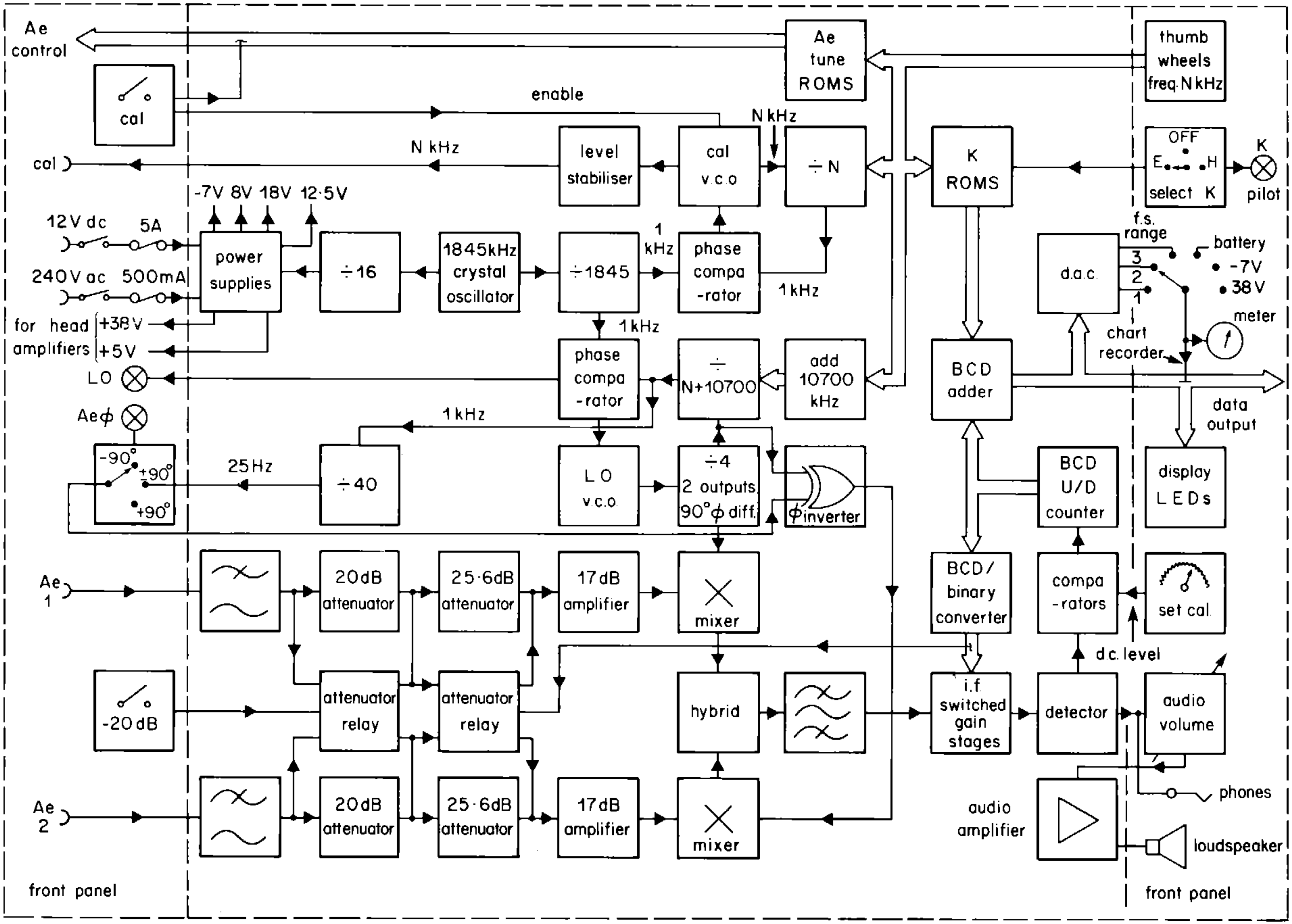

Fig. 4 - Block schematic of l.f./m.f. receiver

1.61MHz and at least 70dB down for frequencies above 3.2MHz. The next stage is a pair of 20dB attenuators which are switched in by a front panel control and have the main purpose of protecting against mixer overload when in the presence of a high unwanted signal level. These attenuators also extend the dynamic range of the receiver. The following attenuators of 25.6dB are switched in by the automatic-gain logic of the receiver. The 17dB amplifiers raise the level of the signal (and front-end noise) to take account of the losses in the mixers, hybrid and filter which follow. This reduces the extent to which the noise performance of the receiver is dictated by the first i.f. stage. The amplifier also has input and output impedances of 50 ohms to ensure satisfactory operation of previous stages and the following mixer.

The mixers are a pair of commercially available diode rings giving high conversion gain and low carrier leak. The amplitude and phase-frequency responses of the units are closely matched over a wide temperature range.

Signals applied in-phase at the two aerial inputs arrive in quadrature at the hybrid transformer in which they are combined. The phase difference is obtained by feeding the mixers with two local oscillator signals in quadrature, generated from a voltage-controlled oscillator (v.c.o.) at 4 times the required frequency.* A phase inverter allows either of the local oscillator signals to have a phase lead of 90° or for the sense of the quadrature to alternate at 25Hz. If phase errors exist in the system perfect quadrature will not be obtained and the method of alternating the form of quadrature reduces the errors which may be introduced for this reason. Also, if the received signals are coming from more than one source, producing an elliptical field locus for the horizontal magnetic field, the phase alternation ensures that left and right-hand senses of rotation are treated equally.

The hybrid is followed by a commercial crystal filter with a bandwidth of ± 4kHz. The i.f. amplifier has electronically switched gain steps which are in a binary sequence from 0.2dB to 25.6dB plus an additional 25.6dB step which with the switched r.f. attenuator gives a further (51.2dB) binary step. Thus it is possible to obtain automatic attenuations from 0 to 102.2dB in 0.2dB steps. The detector is a full-wave rectifier type to give good linearity so that its d.c. output is independent of the modulation depth. The detector ouput is compared with a stable d.c. voltage which may be adjusted by a "screwdriver preset" on the front panel. The outputs of the comparators control an up/down counter with b.c.d. output which, after conversion to binary, brings in or takes out the gain stages until the detector output is within one gain step from the reference level. The b.c.d. output also goes to an adder to be increased by an amount K (in decibels) so that the result is the field strength as defined above.

The necessary "K factor", as it is known, differs between the whip and loop aerials, and depends on the frequency (which is selected on the thumbwheels). All the "K factors" are held in read-only memories (ROMs) and a "select K" switch is provided which is set to "E" when measuring electric fields and "H" when measuring magnetic fields. If the "select K" switch is in the "OFF" position a constant is added so that the receiver acts as an r.f. microvoltmeter. The output of the adder is displayed by l.e.d.s on the front panel and also goes to a 25 way D-connector. Also a digital-to-analogue converter (d.a.c.) is provided to drive a front panel meter and to provide an output for a chart recorder.

The local oscillator (l.o.) frequency is synthesised. The basic v.c.o. has a frequency of 4 (N + 10700) kHz, where N is the value selected on the thumbwheels, and operates within a phase-locked loop. The reference frequency of 1845 kHz is derived from a crystal oscillator. This crystal oscillator also provides a control frequency for the calibration oscillator and the power supply.

The power supply is fed from a vehicle battery or from 240 Volts 50 Hz mains. Since the vehicle battery may vary from 10 to 17 Volts the supply is first series regulated to 8V. This supplies a d.c/d.c. converter whose frequency is dictated by the crystal oscillator which is divided by 16 outside the power supply and by a further 2 inside. Thus the operating frequency of the d.c./d.c. converter is 57.65625kHz, a frequency chosen to reduce interference problems.

Fig. 5 is a photograph of the receiver where each of the front panel controls and displays, described above, can be seen.

5. TUNING AND CALIBRATION

As mentioned earlier, the aerials are tuned by a set of 8 capacitors in a binary scale. The required tuning capacity value is stored in a ROM as a function of frequency, in the same way as the K factors for *E* & *H*. New values are stored only every 4 kHz

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*The local oscillator and associated circuits were developed by P.W. Fraser.

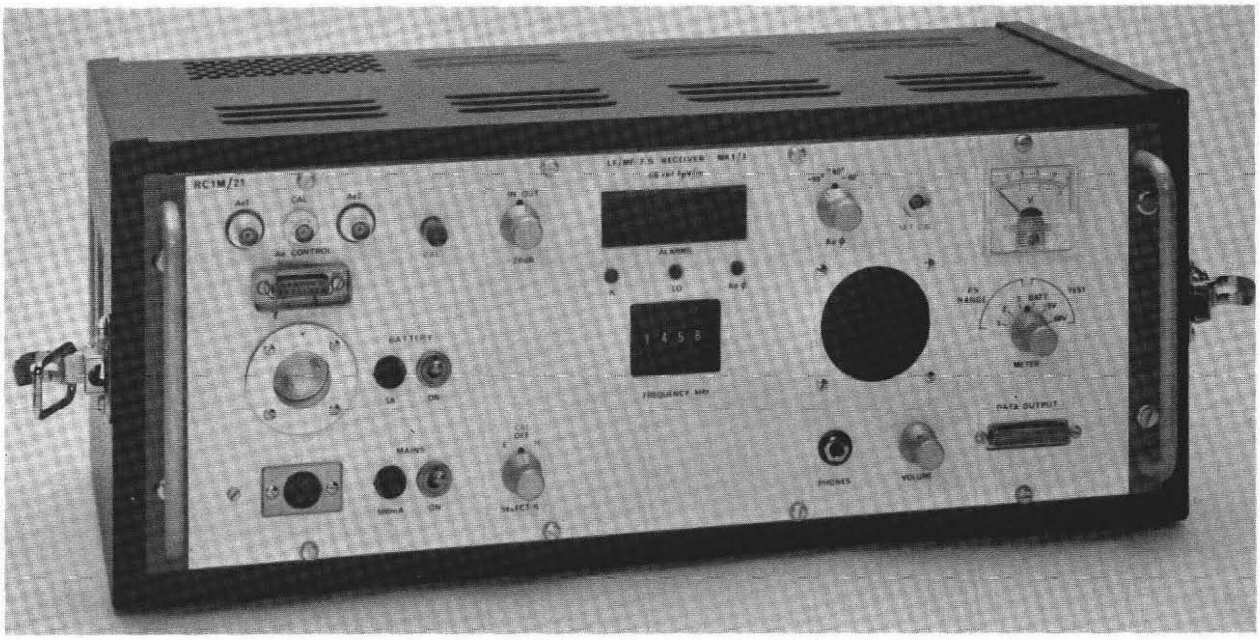

Fig. 5 - Front panel of receiver.

in order to economise on memory. The K values show small variations from a smooth function of frequency, owing to the quantisation of the tuning into 5 pF capacitance steps and 4kHz frequency steps.

The receiver was calibrated by installing it in a vehicle and placing it in an electromagnetic field of known strength. The method of obtaining a known field is described in Reference 6. Measurements were taken at several points in the known field and at several frequencies in the l.f. and m.f. bands. Thus the K factors were obtained at these spot frequencies.

It was not practical to make known field measurements at every 1 kHz frequency step, so the fine detail variations in K were obtained by measuring the responses of the aerials to the built-in calibration oscillator. This was done under the control of a microprocessor system which was programmed for the purpose.* The gain of the i.f. amplifier was fixed and a digital voltmeter connected to the detector output. The microprocessor set the receiver to each frequency in turn and punched the voltmeter reading on paper tape. The detector characteristic was measured and the processing of the results was done by computer. Finally, the known-field and microprocessor results were combined to give the K factors for storage in the ROMs.

The aerial tuning capacity for each 4 kHz step was obtained by the microprocessor, using an optimisation program. During this procedure the microprocessor was given control of the tuning.

6. CONCLUSIONS

The receiver represents an extension of the design philosophy of the u.h.f. and Band II measuring receivers. Digital techniques have been used extensively to simplify the operation of the receiver and to make the results more reliable. Attention has been paid to making the sensitivity of the receiver stable; the gain of the various stages is determined largely by resistor ratios. As a result, the calibration only needs to be checked occasionally and does not normally need adjustment. The accuracy of measurement depends largely upon the initial calibration, which is within about ± 1 dB.[6] The receiver can take measurements rapidly, e.g. on the move in a car, and is suitable both for field-strength survey work and for propagation studies.

7. REFERENCES

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Appendix

OPERATION OF THE RECEIVER

1. Switch on in accordance with the input power supply.

2. Dial up 1000 kHz.

3. Ensure K select to "off".

4. Ensure -20dB switch set to "out".

5. Connect short double ended 50 ohm BNC from Cal. to Ae.1.

6. Press red switch.

7. Check 100 dB ± 0.2 on L.E.D.'s. This can be achieved by the "set cal" screwdriver pre-set, but it is inadvisable to go straight to this without first considering if everything else is in order.

8. Change BNC to Ae.2 and see if 100 dB ± 0.4 dB is obtained.

9. Connect up aerials to be used.

10. Select frequency to be measured.

11. a) Loops: with only "red" aerial plugged in carry out checks of point 12 below, repeat with only "blue" aerial connected.

    b) Whip: carry out checks of point 12.

12. Press red "cal" button and check L.E.D.'s in agreement with Table supplied with receiver within ± 0.4 dB. If not a fault is to be suspected, so do not make up discrepancy with "set cal" pre-set.

13. Switch K select to "*E*" or "*H*" as appropriate

14. When close to a powerful transmitter mixer overload can occur, which can be recognised from the audio output. It is then necessary to switch in the manual 20 dB attenuator.

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